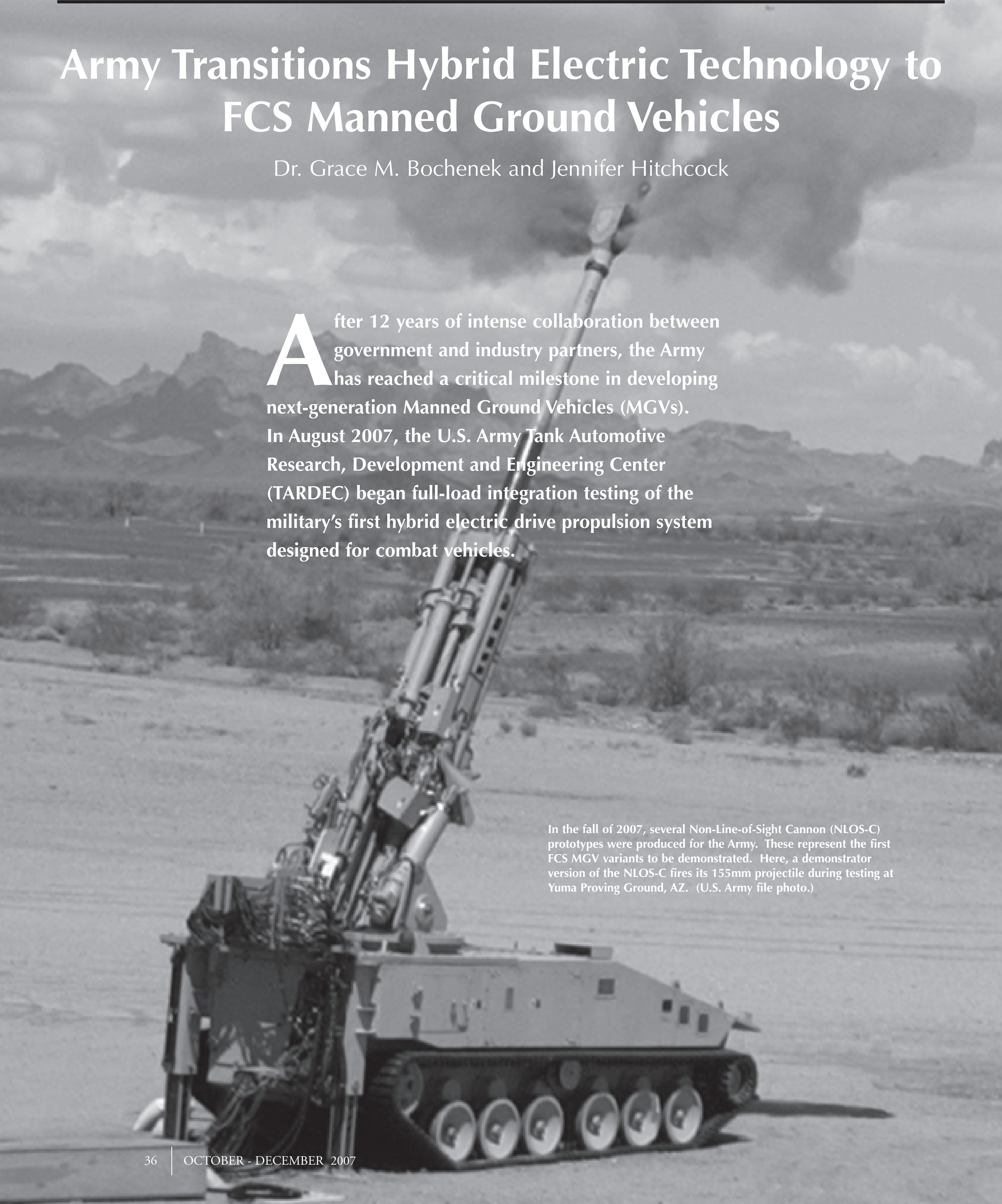
Army Transitions Hybrid Electric Technology to FCS Manned Ground Vehicles

Dr. Grace M. Bochenek and Jennifer Hitchcock

After 12 years of intense collaboration between government and industry partners, the Army has reached a critical milestone in developing next-generation Manned Ground Vehicles (MGVs). In August 2007, the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) began full-load integration testing of the military's first hybrid electric drive propulsion system designed for combat vehicles.



In the fall of 2007, several Non-Line-of-Sight Cannon (NLOS-C) prototypes were produced for the Army. These represent the first FCS MGV variants to be demonstrated. Here, a demonstrator version of the NLOS-C fires its 155mm projectile during testing at Yuma Proving Ground, AZ. (U.S. Army file photo.)

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This new propulsion system will drive and provide electrical power to all eight Army Future Combat Systems (FCS) MGV variants. As explained by MG Charles Cartwright, Program Manager FCS Brigade Combat Team (BCT), "Combat vehicles need significantly more power than commercial platforms. To meet those requirements, the Army and a robust set of industry partners have pioneered the development of advanced hybrid propulsion systems."

This work directly impacts the Army's ability to enhance force protection and more rapidly execute battlefield maneuver.

The Army's Research, Development and Engineering Driver Behind Hybrid Drive

TARDEC has been the Army's chief architect throughout the research, development and testing of this new powerpack, guiding it from concept to actual hardware. The FCS MGV hybrid electric drive system consists of an engine, generator, generator dissipater controller, traction drive system, energy storage system and cooling system.

The system is built around a 5.5-liter, 5-cylinder, 440-kilowatt (kW) diesel engine that can operate at speeds of up to 4,250 revolutions per minute (rpm), compared with maximums of 2,600 to 3,000 rpm typical of today's diesel engines. At about the same gross horsepower (hp), the engine is almost 50 percent smaller in volume and weight, and produces more than a 60 percent increase in engine speed than the diesel engine that currently powers the Bradley Fighting Vehicle (BFV).

The new engine itself, however, will not directly drive the Army's future MGVs. Its job is to provide power via the generator to all the vehicle's electrical systems. In these vehicles, the hybrid drive system will propel the vehicle via traction motors, which is a completely new way of maneuvering on the battlefield. The system's advanced energy storage, power generation, regenerative braking and power management technologies will also provide the power necessary to support each vehicle's nonprimary power requirements.

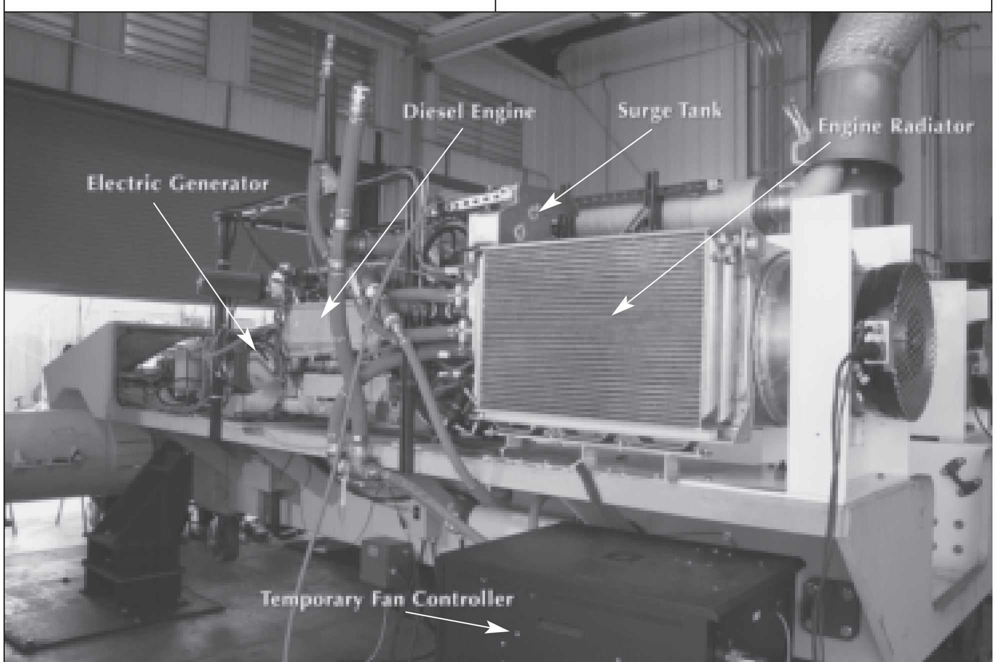
The system will allow the vehicles to operate in silent watch and silent run modes, and will improve vehicle dash capability while enhancing low-speed maneuverability. Finally, by decoupling the engine from the drive train architecture, the system has been designed so that its components are positioned throughout the vehicle platform in a way that maximizes interior space availability. This will provide Soldiers with more room to move and perform mission-critical tasks.

Power On

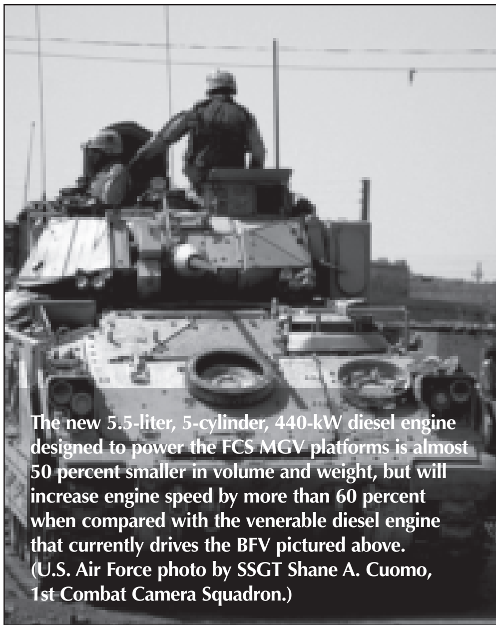
Headquartered just outside Detroit, MI, the automotive capital of the world, TARDEC has led the development of propulsion technologies for Army ground vehicles for more than 50 years. Propulsion technologies are the engines, transmissions, generators, air cleaners, cooling systems and energy storage technologies that put the "mobility" in ground vehicle platforms. Increasingly, these same technologies are also on the hook to answer increasing nonprimary power requirements (requirements not specifically dedicated to propulsion), such as those that power a vehicle's lethality, survivability and communications systems.

As each of these requirements has evolved and escalated over time, so has the Army's need for more advanced primary and nonprimary power systems. Anticipating these propulsion system requirements before the Army's transformation process began, TARDEC had already amassed the expertise and tools to respond.

By the late 1980s, it was clear that hybrid electric technologies — a marriage of combustion and electrical components to generate vehicle power — were going to be key in powering the next generation of military ground



This side view of the fully integrated FCS propulsion system undergoing tests on the "Hot Buck" at TARDEC's P&E SIL shows some of the key components TARDEC has engineered. The Hot Buck is a one-of-a-kind virtual FCS test bed platform for full-load testing. (Photo courtesy of TARDEC.)



The new 5.5-liter, 5-cylinder, 440-kW diesel engine designed to power the FCS MGV platforms is almost 50 percent smaller in volume and weight, but will increase engine speed by more than 60 percent when compared with the venerable diesel engine that currently drives the BFV pictured above. (U.S. Air Force photo by SSGT Shane A. Cuomo, 1st Combat Camera Squadron.)

vehicles. Those technologies are where they are today in large part because TARDEC scientists, engineers and administrators — either directly or through funding of innovative industry and academic programs — have led the way in maturing engine, electric motor, electronic architecture and energy storage systems to meet anticipated military vehicle power demands.

The Engine Block as Building Block

As a principal member of the FCS "One Team" partnership, which included FCS (BCT), the Army Research Laboratory (ARL), Boeing, BAE Systems, General Dynamics Land Systems and Science Applications International Corp., TARDEC initially brought its expertise and leadership to bear in supporting the FCS Engine Technology Science and Technology Objective (STO).

The Engine Technology STO's goal was to develop a high power density (net power per total system volume) engine with reduced engine size, weight, heat rejection and high coolant temperatures. When improved, each of these factors provides the critical parameters needed to advance overall propulsion system power density. For example, higher coolant temperatures and lower heat rejections allow for a much smaller cooling system and less cooling fan power losses. This translates to greater power density and, therefore, to more power to the tracks or wheels for greater mobility.

The outcome of the Engine Technology STO, which concluded in 2005, was a 4.4-liter, in-line 4-cylinder diesel engine that met several critical performance goals.

- It provided six net hp/cubic foot, compared with currently fielded military systems that provide three net hp/cubic foot. This metric — net hp/cubic foot — represents the entire propulsion system's output.
- It met an unprecedented displacement goal (the engine's output to volume ratio) of 2 hp/cubic foot, which was more than 40 percent less displacement than any commercial or military engine that had come before.
- It was able to generate 410 kW of prime power.

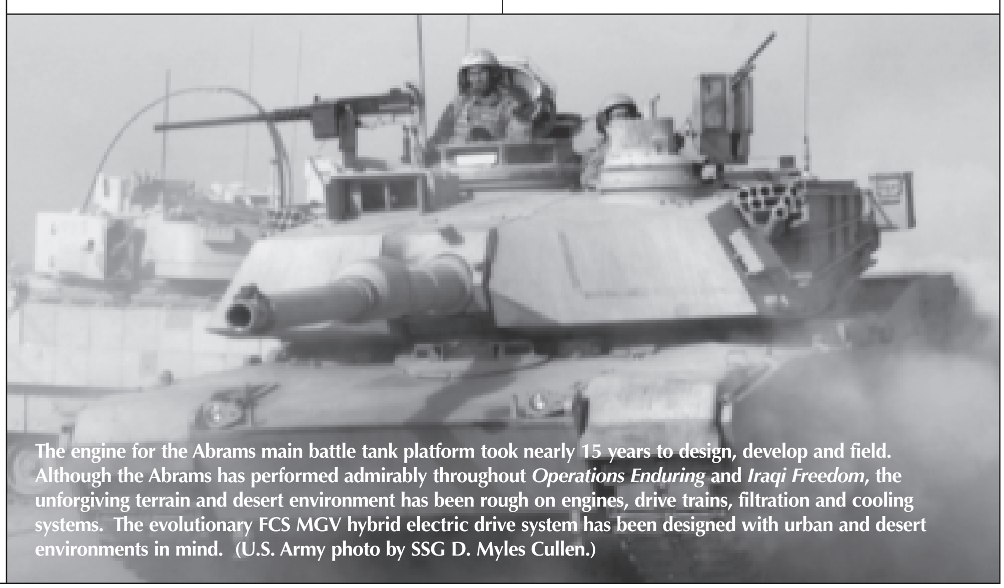
However, the Army's biggest challenge was in meeting the program's high-speed combustion goals and high operational coolant temperature (267 F) requirements. The high engine speeds of the FCS hybrid electric powerpack provided the solution. Those higher speeds would also allow for a lighter, smaller generator, which would keep the propulsion system volume goals on target.

Eventually, the technology from the Engine Technology STO was transitioned to develop a 5.5-liter, 5-cylinder engine that would produce up to 440 kW of prime power with a 10-percent growth margin, to ensure coverage of evolving FCS ground vehicle platforms and operational concepts. In less than a year, the new design went from blueprint to hardware.

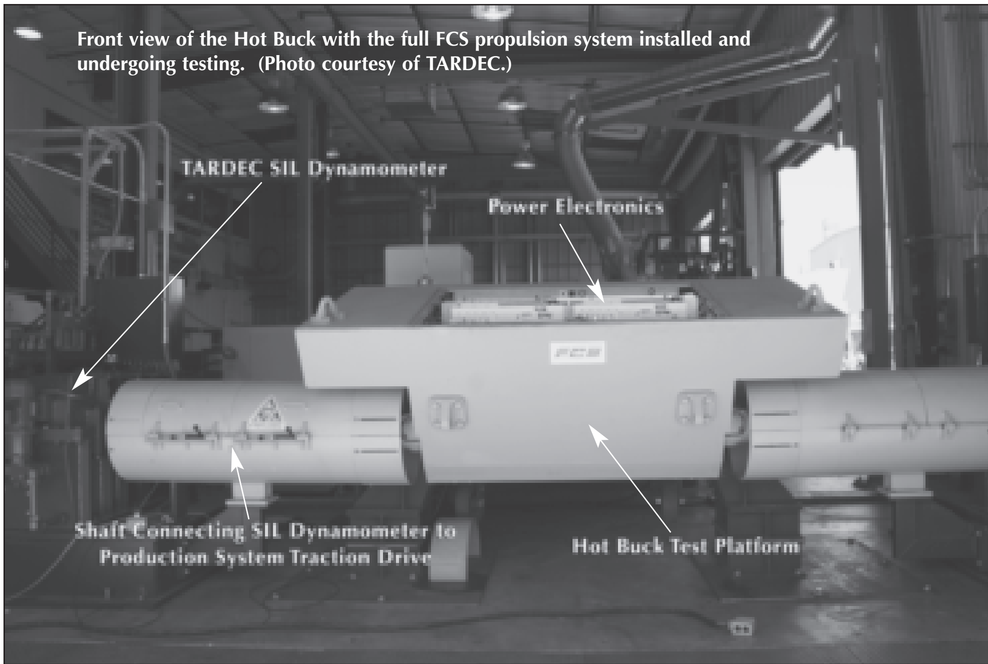
Bringing It All Together

As important as the engine was to the program's success, it was still only one of many components that would eventually comprise the FCS propulsion system. In 2004, under the Hybrid Electric for FCS Army Technology Objective, the Army expanded the FCS propulsion program to improve cooling reliability and efficiency and to increase the power and energy density of the system's other components. TARDEC was again prepared for the tasks at hand, having heavily invested over many years in electric motor, air cleaner, cooling system and advanced battery technologies.

To enable silent watch and silent maneuver operations, and to provide additional



The engine for the Abrams main battle tank platform took nearly 15 years to design, develop and field. Although the Abrams has performed admirably throughout *Operations Enduring* and *Iraqi Freedom*, the unforgiving terrain and desert environment has been rough on engines, drive trains, filtration and cooling systems. The evolutionary FCS MGV hybrid electric drive system has been designed with urban and desert environments in mind. (U.S. Army photo by SSG D. Myles Cullen.)



Front view of the Hot Buck with the full FCS propulsion system installed and undergoing testing. (Photo courtesy of TARDEC.)

boost power, TARDEC accelerated its already advanced energy storage research and development work to further develop lithium ion battery technologies. In collaboration with ARL, TARDEC segregated 880 individual program tasks into 5 categories, including mixing, coating and winding; electrolyte filling; circuit breaker bussing and closing; electrical formation; and battery assembly. Since 2004, the team has made tremendous strides toward increasing power density to 3 kW per kilogram (kg); increasing energy density to 150 watt-hours/kg; reducing production costs; and improving overall battery performance, safety and reliability.

Most importantly, as the Army's systems integrator for ground vehicle platforms, TARDEC played a key role in evolving each of these parts of the system from component to subsystem and, finally, to full system capability. TARDEC began the process at the component and subsystem levels at its Engine Generator Test Lab in Michigan. In August 2007, the process migrated to TARDEC's state-of-the-art Power and Energy System Integration Laboratory (P&E SIL) in Santa Clara, CA. This represents the first time that real FCS hardware has been integrated into a full hybrid electric power system in a vehicle platform (see *Army Invests in Testing Facilities to Support Current and Future Technologies*, Page 40).

True Technology Transfer

While anticipating each new technology requirement, TARDEC has also been evolving its operational and business processes to engage in the vehicle development life cycle at a much earlier stage and to transition technologies to program executive officers and product managers much more rapidly. Nowhere is that more evident than in TARDEC's transition of hybrid electric technologies to the FCS program.

While the engines in the Bradley and Abrams vehicle platforms took upwards of 15 years to design, develop and field, the FCS package has reached this critical point in its development process in only 5 years. This fall, a limited number of systems will be produced for the NLOS-C prototype, the first of the FCS MGV variants to be demonstrated.

TARDEC has been at work for many years to fund and cultivate the expertise, facilities and processes necessary to make this possible. The forethought that went into these investments has resulted in the delivery of the FCS MGV propulsion system in record-breaking time, enabling the rigorous testing, refinement and reengineering processes that are necessary to mature the system as each FCS MGV variant becomes a reality.

Indeed, the process continues. In partnership with ARL, for example, TARDEC continues to pursue such advanced technologies as silicon carbide (SiC) power electronics. These SiC devices will allow component operation at even higher temperatures, thus reducing future cooling system size, weight and power requirements. All of this goes to refining the system that is going to propel and provide auxiliary power to all future MGVs in the Army's fleet.

DR. GRACE M. BOCHENEK is the Director for the U.S. Army's Research, Development and Engineering Command's TARDEC. She holds a B.S. in electrical engineering from Wayne State University, an M.S. in engineering from the University of Michigan and a Ph.D. in industrial engineering from the University of Central Florida. An Army Acquisition Corps member, Bochenek brings more than 20 years of scientific, technical and managerial experience to her position.

JENNIFER HITCHCOCK is the Associate Director for Ground Vehicle Power and Mobility Technology at TARDEC. She holds a B.S. in mechanical engineering from Lawrence Technological University and an M.S. in engineering from Oakland University. Hitchcock has more than 18 years of technical and managerial experience in mobility and power and energy technologies, system engineering, acquisition and program management.